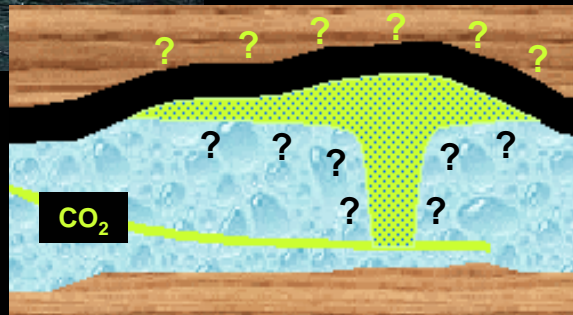
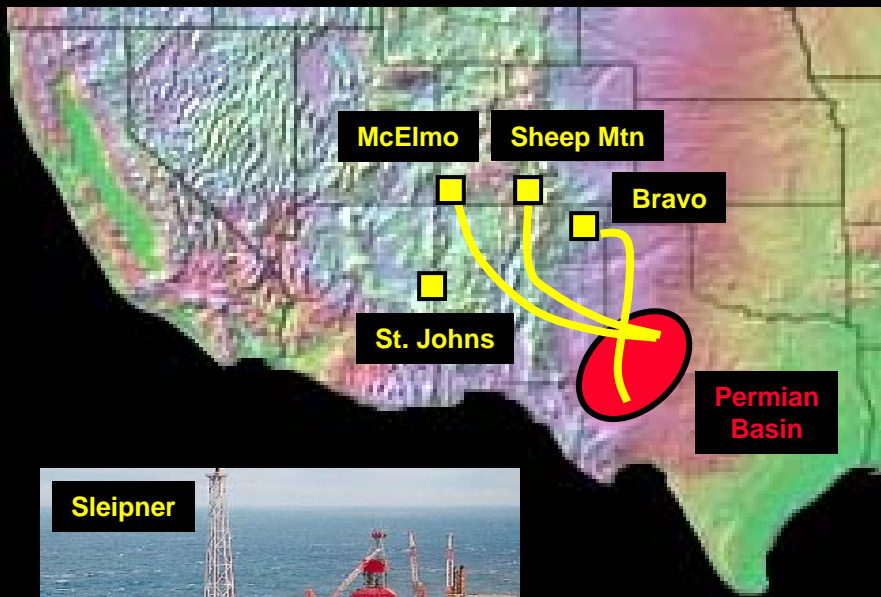


Enhanced isolation performance of geologic CO₂ storage sites through mineral trapping:



Experimental & field confirmation
of model predictions



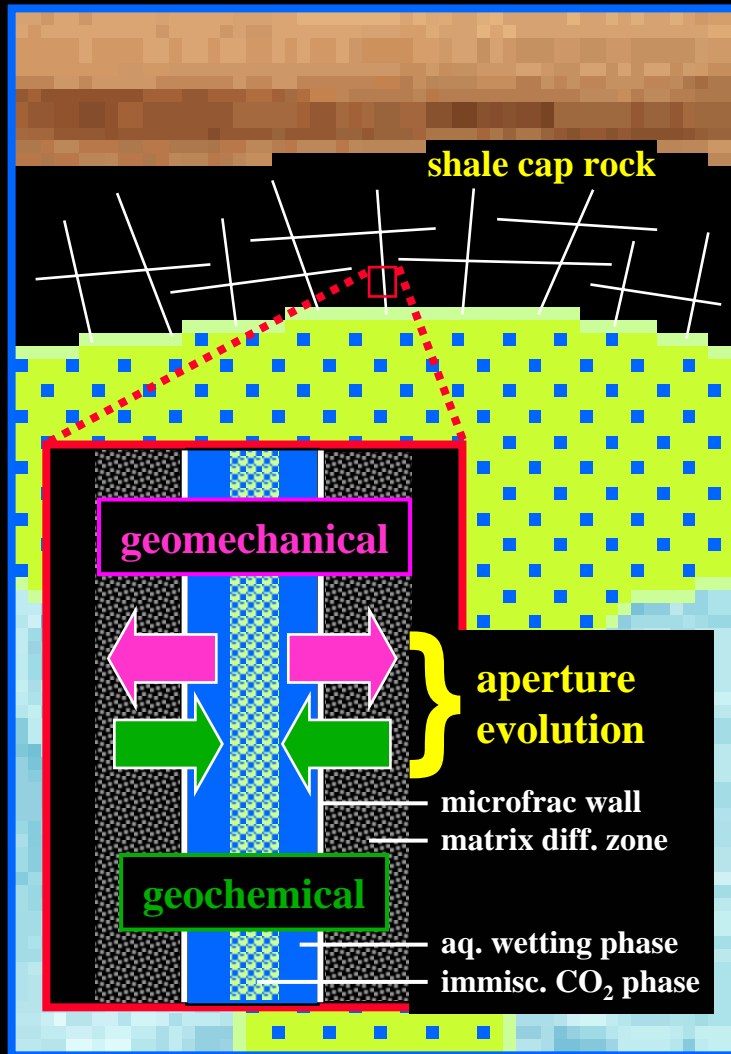
James W. Johnson¹
Kevin G. Knauss¹
S. Julio Friedmann¹
Scott H. Stevens²

¹*Lawrence Livermore Nat'l Lab*

²*Advanced Resources Int'l, Inc.*

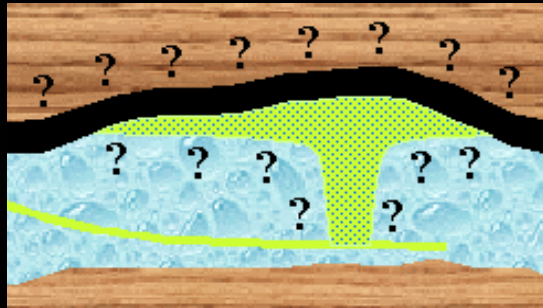
**Fourth Annual Conf. Carbon
Capture & Sequestration
May 2-5, 2005
Alexandria, VA**

Cap rock integrity hinges on the interplay of geochemical & geomechanical processes

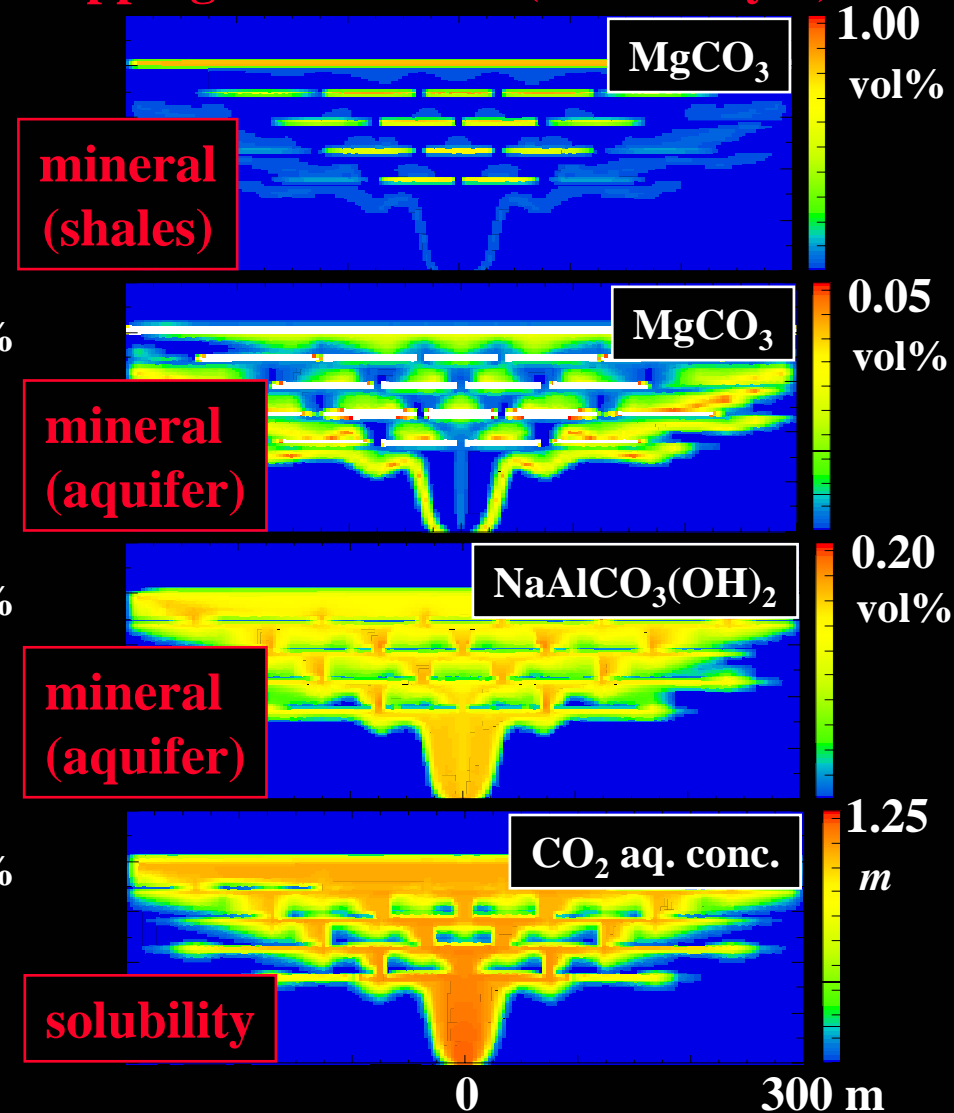
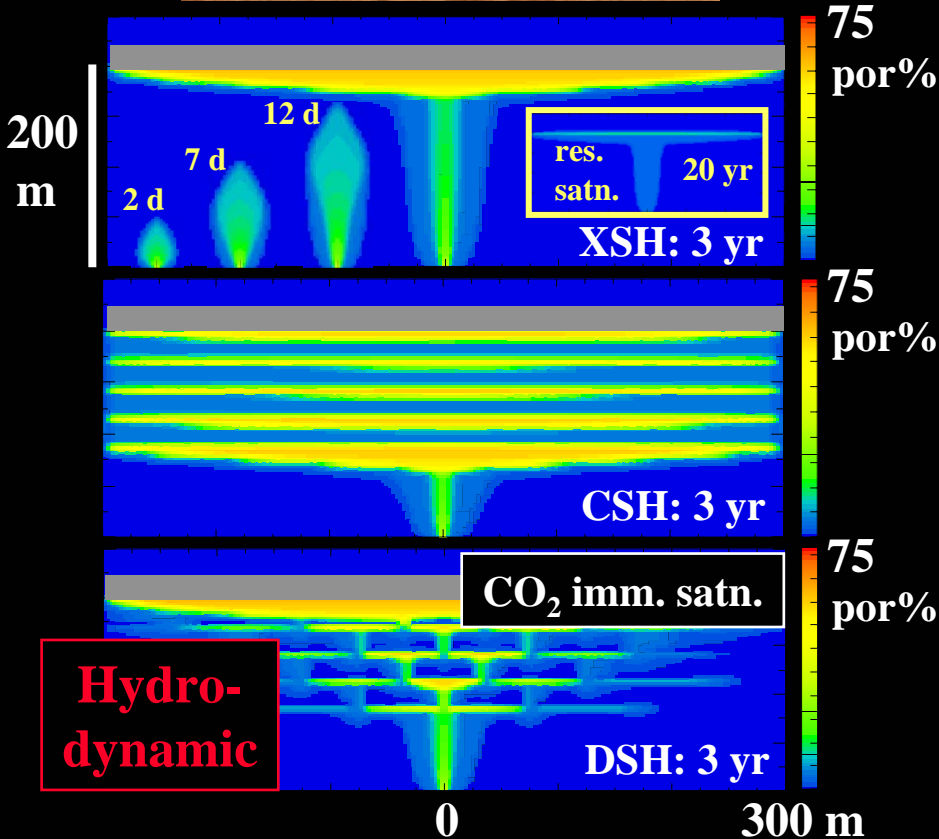


- **Geochemical alteration**
 - ✓ Mineral diss/pptn reactions triggered by the chemical perturbation
 - ✓ Compositional properties of the cap rock, reservoir, & injection fluid
 - ✓ Tends to enhance seal integrity of shale
- **Geomechanical deformation**
 - ✓ Microfrac mobilization triggered by the pressure (effective stress) perturbation
 - ✓ CO₂ influx rate, duration, & focality; reservoir perm & lateral continuity
 - ✓ Tends to degrade seal integrity of shale
- **Relative effectiveness controls the evolution of cap rock integrity**

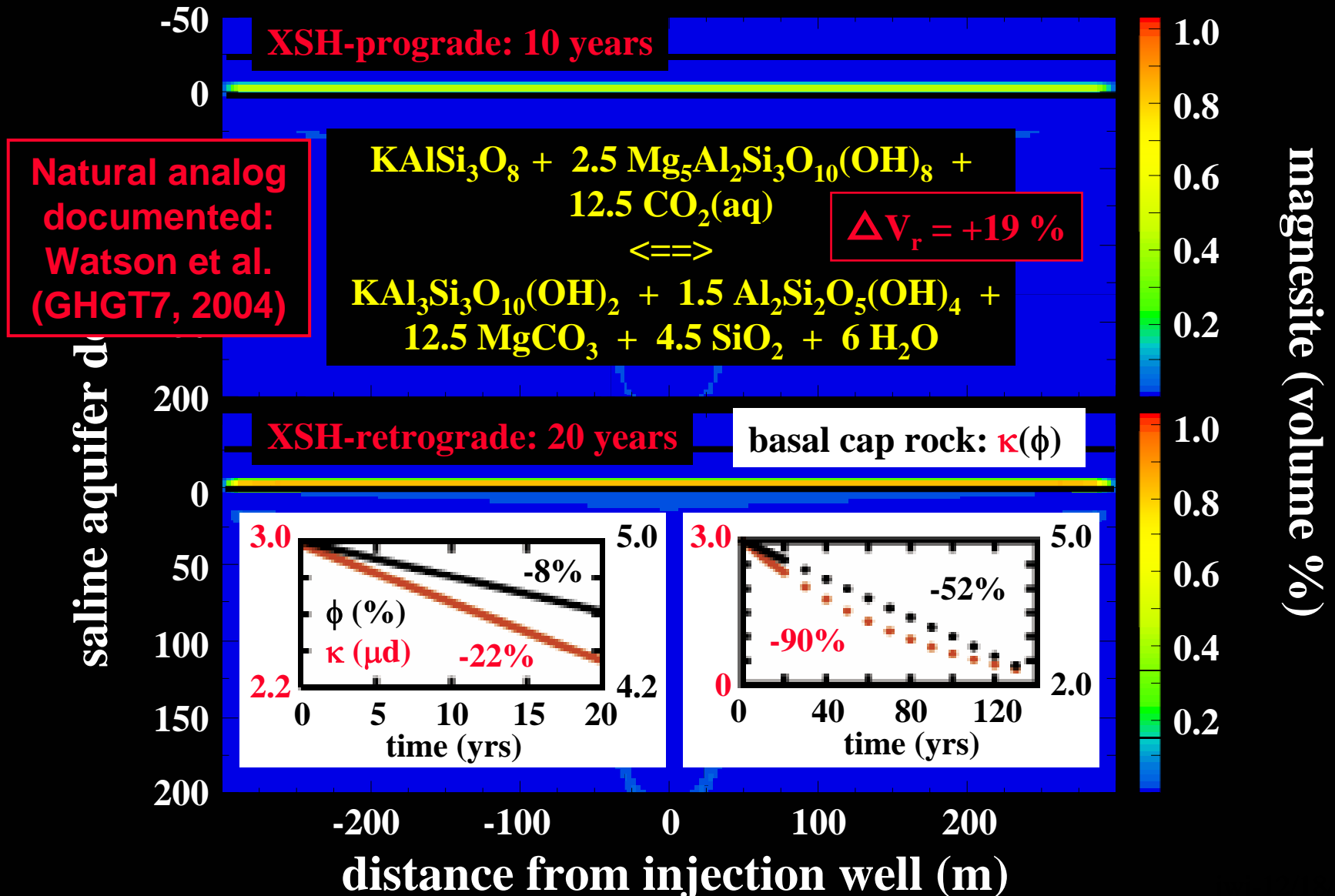
Reactive transport modeling of geologic CO₂ sequestration at Sleipner



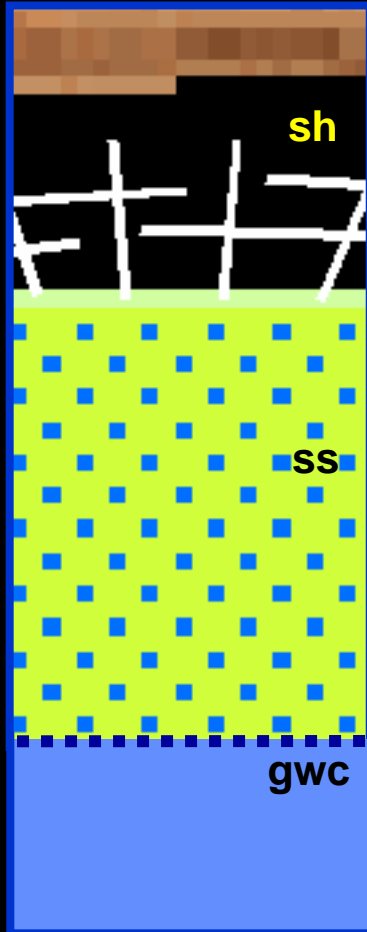
trapping mechanisms (DSH: 20 yrs)



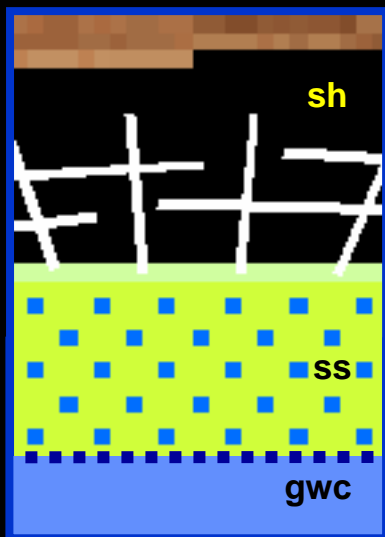
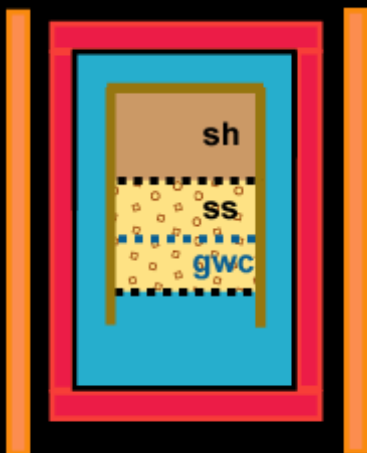
Mineral trapping significantly enhances the seal integrity of shale cap rocks



Batch reactor experiments provide a physical analog to cap-rock/reservoir interface environs

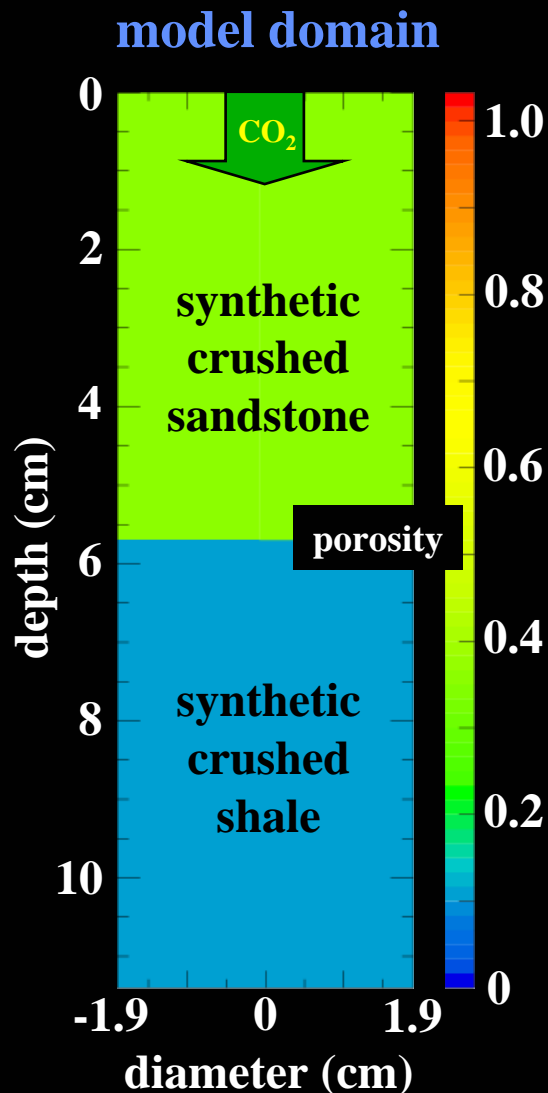


Integrated expt/modeling assessment of key mineral-trapping predictions



- **Reactive transport modeling**
 - ✓ Conduct spatially scaled Sleipner simulations
 - ✓ Identify optimal experimental P-T-t framework
 - ✓ Predict geochem evolution (pre- & post-expt)
- **Baseline experiments**
 - ✓ Mimic Sleipner models at elevated P-T
 - ✓ Synthetically-prepared samples
 - ✓ Known grain size & BET surface areas
- **Initial baseline variants**
 - ✓ Address key compositional variations
 - ✓ Carbonate cements, silicate Fe/Mg ratio
- **Secondary baseline variants**
 - ✓ Address natural system complexities
 - ✓ Complex solid solns, trace mins, heterogeneity
 - ✓ Frio, McElmo, & Teapot Dome core samples

Reactive transport modeling of baseline experiments using NUFT/GEMBOCHS



- **Synthetic crushed sandstone**

- ✓ 35% porosity, 3-darcy perm
- ✓ 80% qtz, 10% K-feld, 5% plag-Ab80, 3% muscovite, 2% phlogopite
- ✓ seawater-like fluid comp

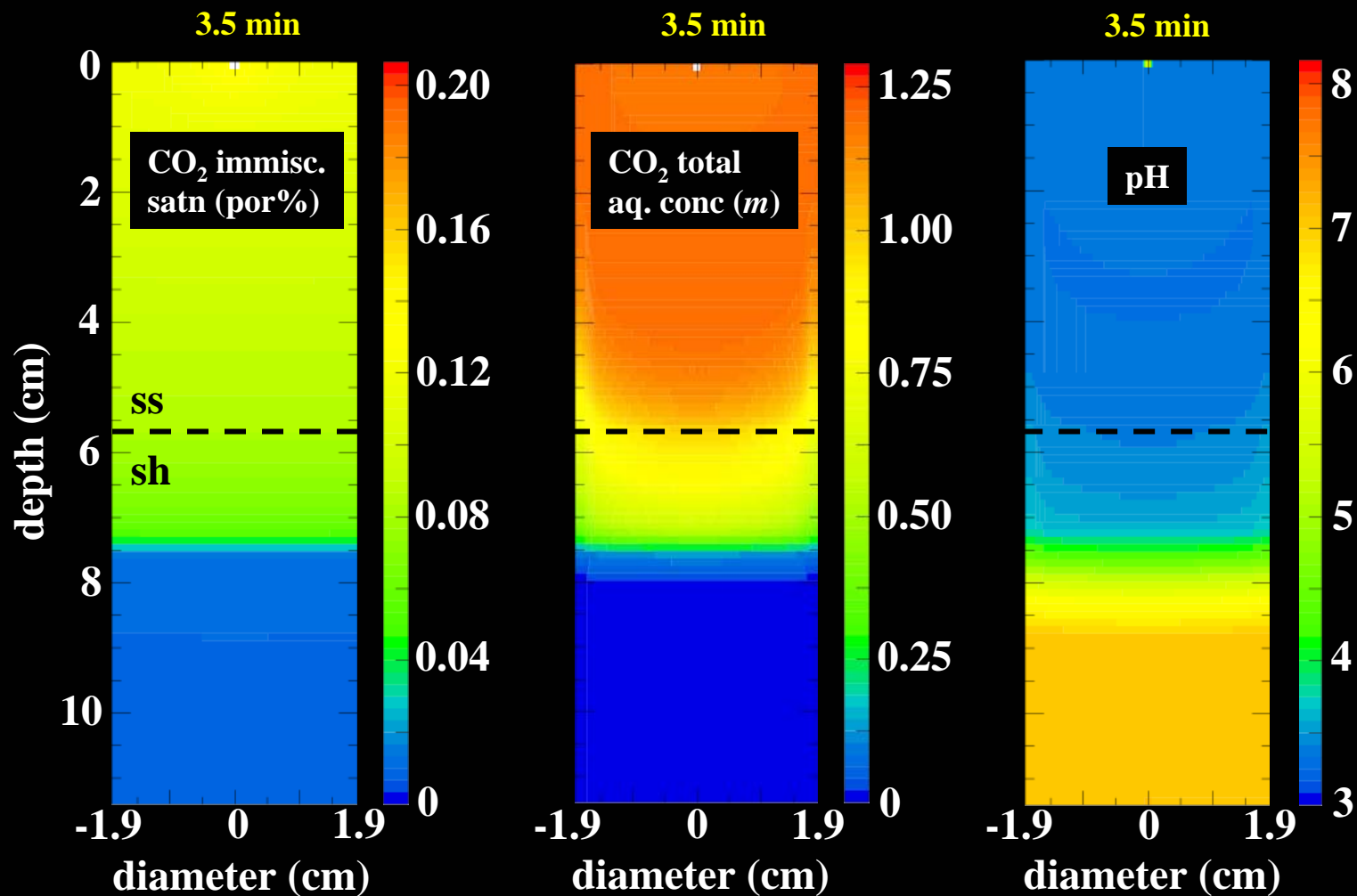
- **Synthetic crushed shale**

- ✓ 10% porosity, 0.75-darcy perm
- ✓ 60% clays (50% muscovite, 10% Mg-chlorite), 35% quartz, 5% K-feldspar
- ✓ fluid composition identical to sandstone

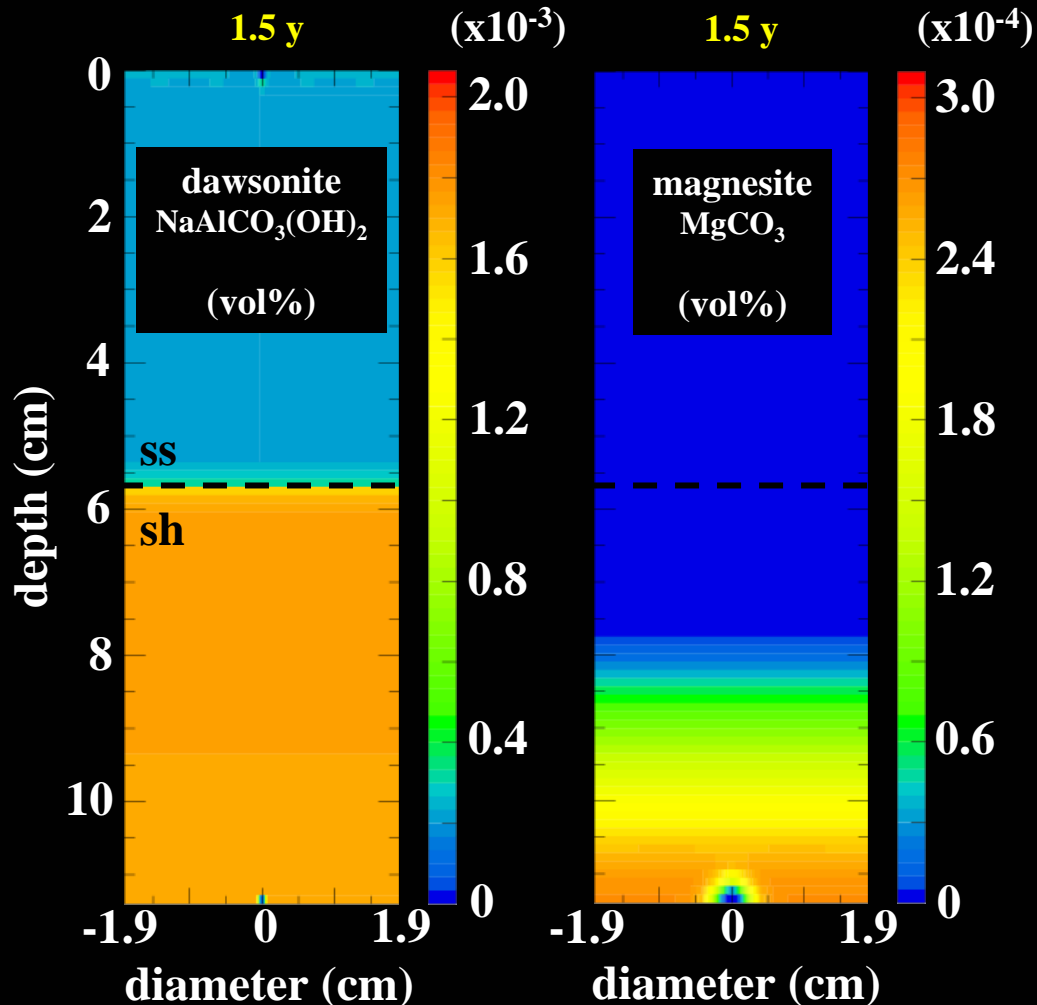
- **Simulation P-T & influx conditions**

- ✓ 37°C, 100 bars
- ✓ CO₂ influx event: minutes
- ✓ Post-influx duration: 1.5 y

Favorable conditions for mineral trapping are established during brief influx event



Slow mineral diss/pptn kinetics at typical field conditions necessitate elevated expt'l temps



- **Dawsonite**

- ✓ Initial pptn in sh at 14 d
- ✓ Initial pptn in ss at 87 d
- ✓ Vol.%: 10^{-3} at 1.5 y

- **Magnesite**

- ✓ Initial pptn at in sh at 1 y
- ✓ Vol.%: 10^{-4} at 1.5 y

- **Experimental requirements**

- ✓ Duration: weeks-months
- ✓ Vol.%: 0.5-1.0 (XRD)
- ✓ Elevated temperatures!

The challenge of space, time, & complexity scale-up from lab to field simulations

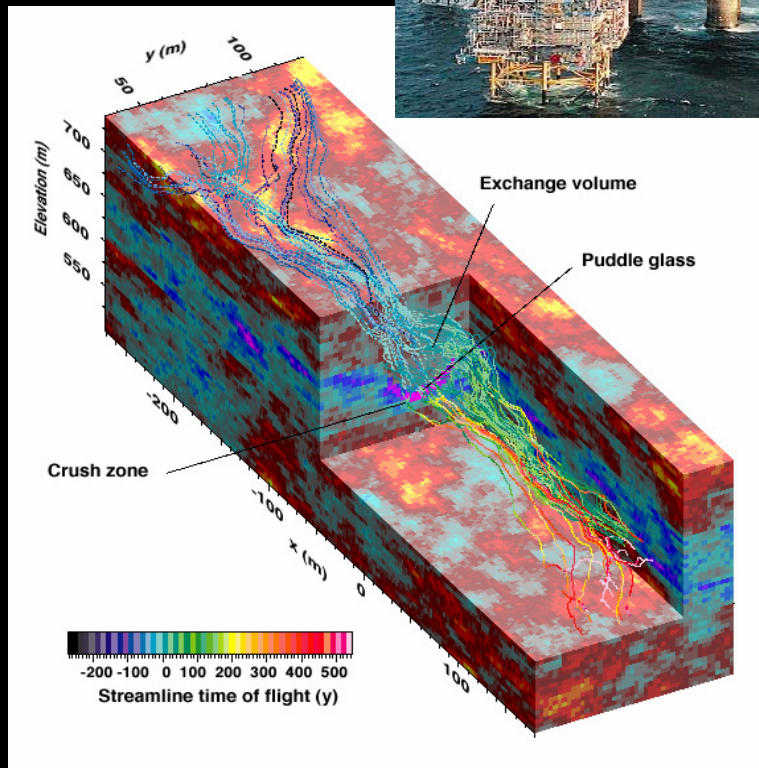


● Lab-scale simulations

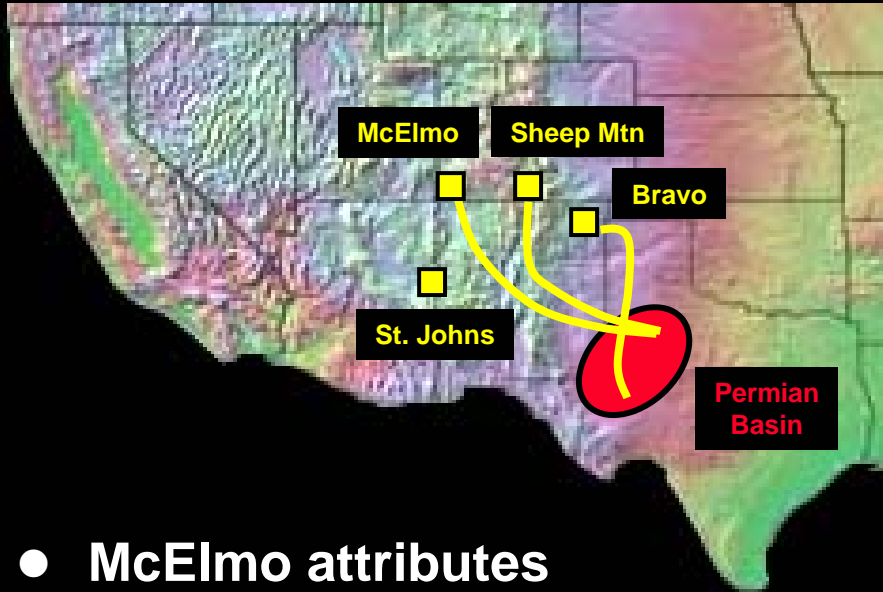
- ✓ Init/bdry conds are established: por/perm, comp, flow, P-T, stress
- ✓ Perturbation event often observed & sampled directly in situ in its entirety
- ✓ Mass/ener redistribution processes often can be evaluated independently
- ✓ Resolution of prediction/observation discrepancies: model fine-tuning

● Field-scale simulations

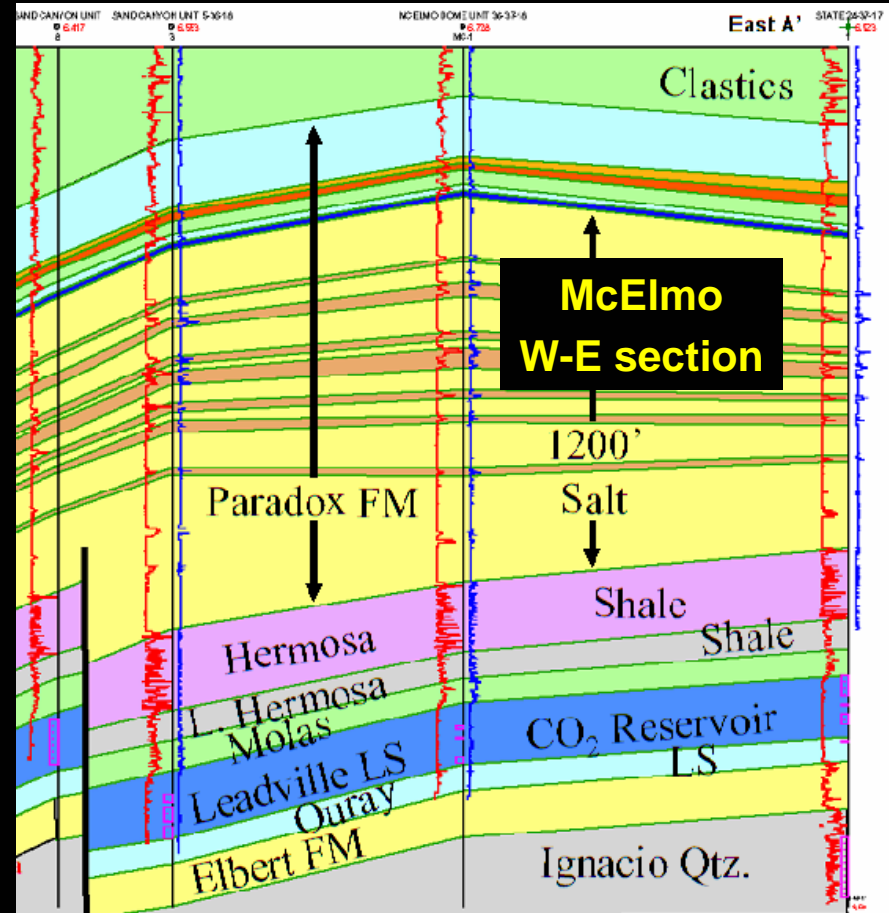
- ✓ Init/bdry conds are poorly known: sparse sampling, extreme heterog.
- ✓ Perturbation event is observed indirectly and sampled at intervals
- ✓ Mass/energy redistribution processes must be evaluated in integrated form
- ✓ Discrepancy resolution: tough to distinguish between domain and integrated-model inadequacies



CO₂ reservoirs represent time-integrated natural analogs to engineered storage sites



- **McElmo attributes**
 - ✓ Largest, best-characterized
 - ✓ 20 m pay zone at 2100 m
- **Owner/operator**
 - ✓ Kinder Morgan CO₂ Co.
- **Data access**
 - ✓ Advanced Resources Int'l



McElmo Dome database, new EarthVision model, & reactive transport modeling program



U. Hermosa

L. Hermosa

Molas

Leadville

Ouray

● Data recently obtained

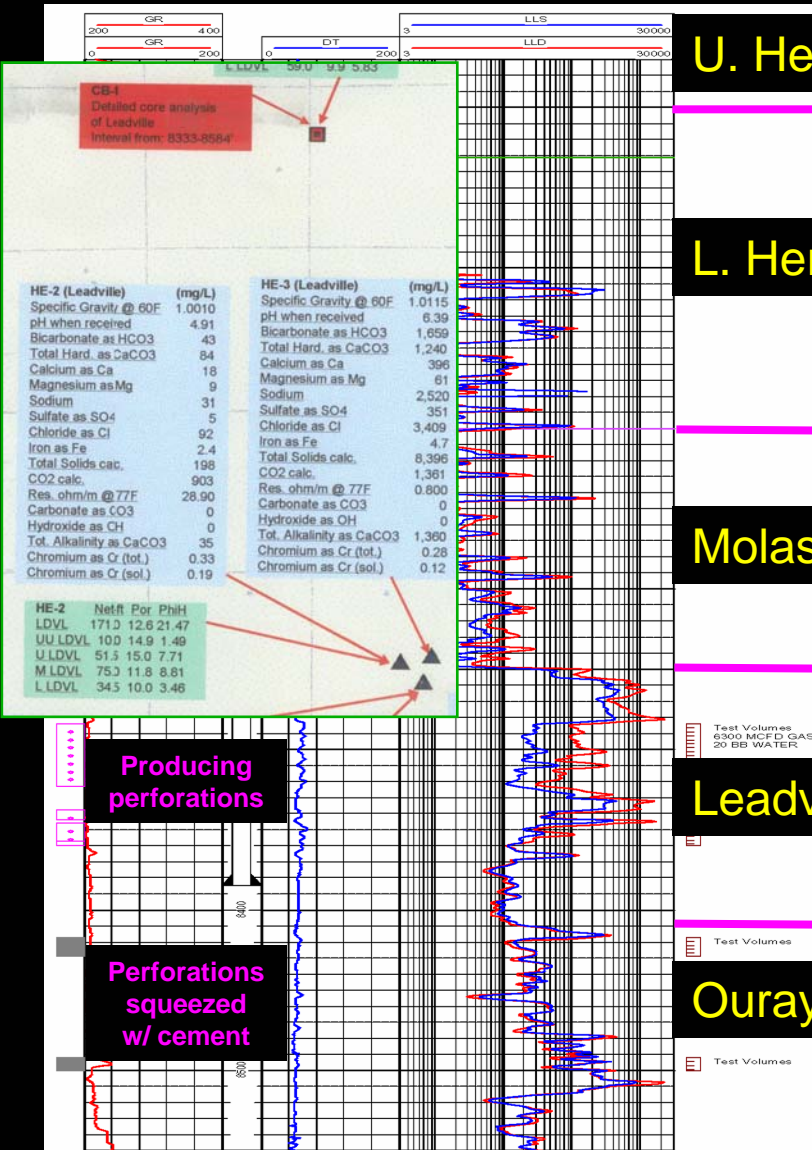
- ✓ Detailed stratigraphy & struct; well locations, logs, & fluid/gas chemistries (created EV model)
- ✓ Reservoir & cap-rock (!) core samples (and perm data): CB-1

● Future data availability

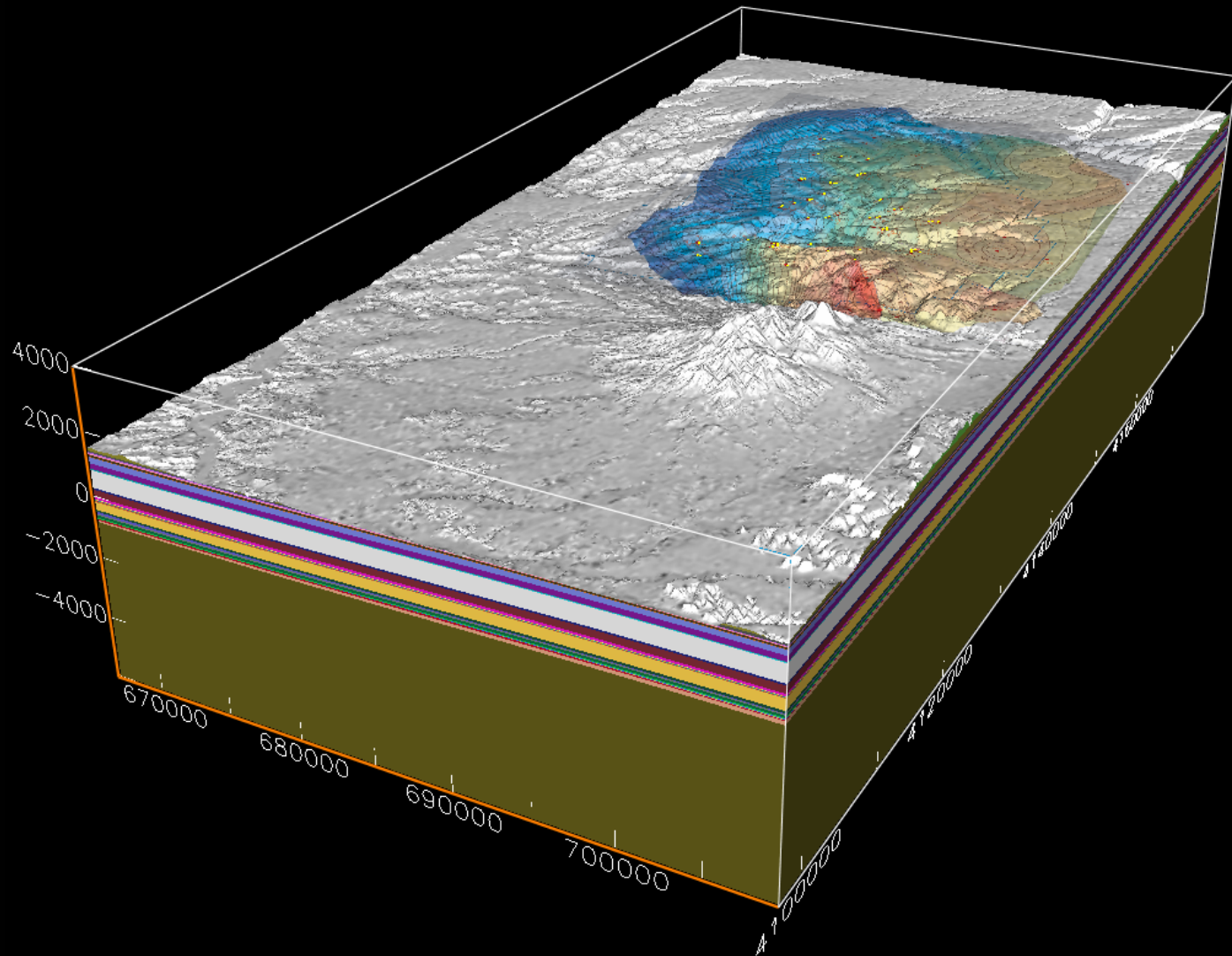
- ✓ Proposed cap-rock sampling program (Stevens et al.)

● Reactive transport modeling

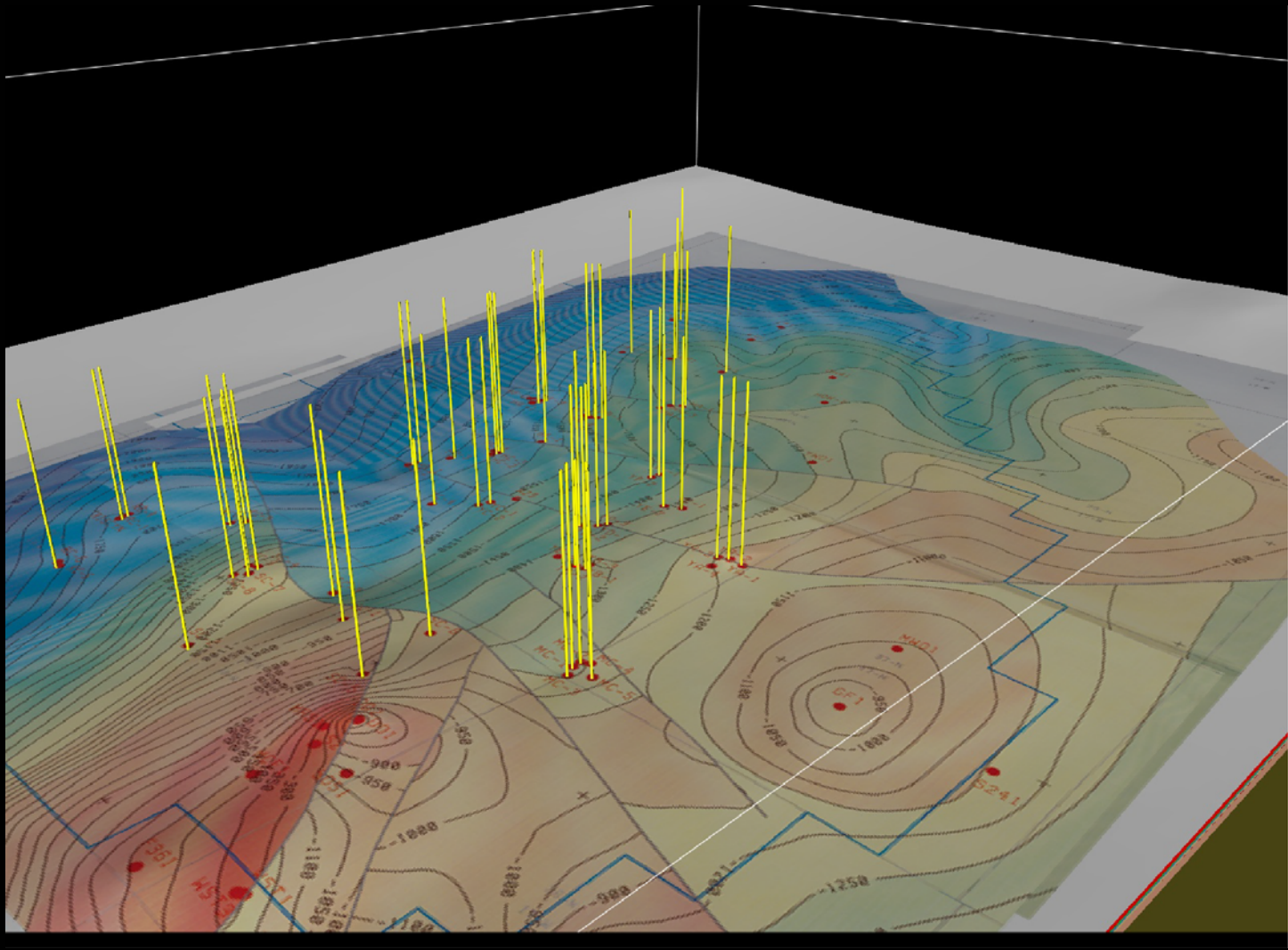
- ✓ Long-term natural CO₂ influx using EarthVision domains
- ✓ Focus: impact of min trapping on por/permeability, reservoir integrity, & cap-rock seal capacity



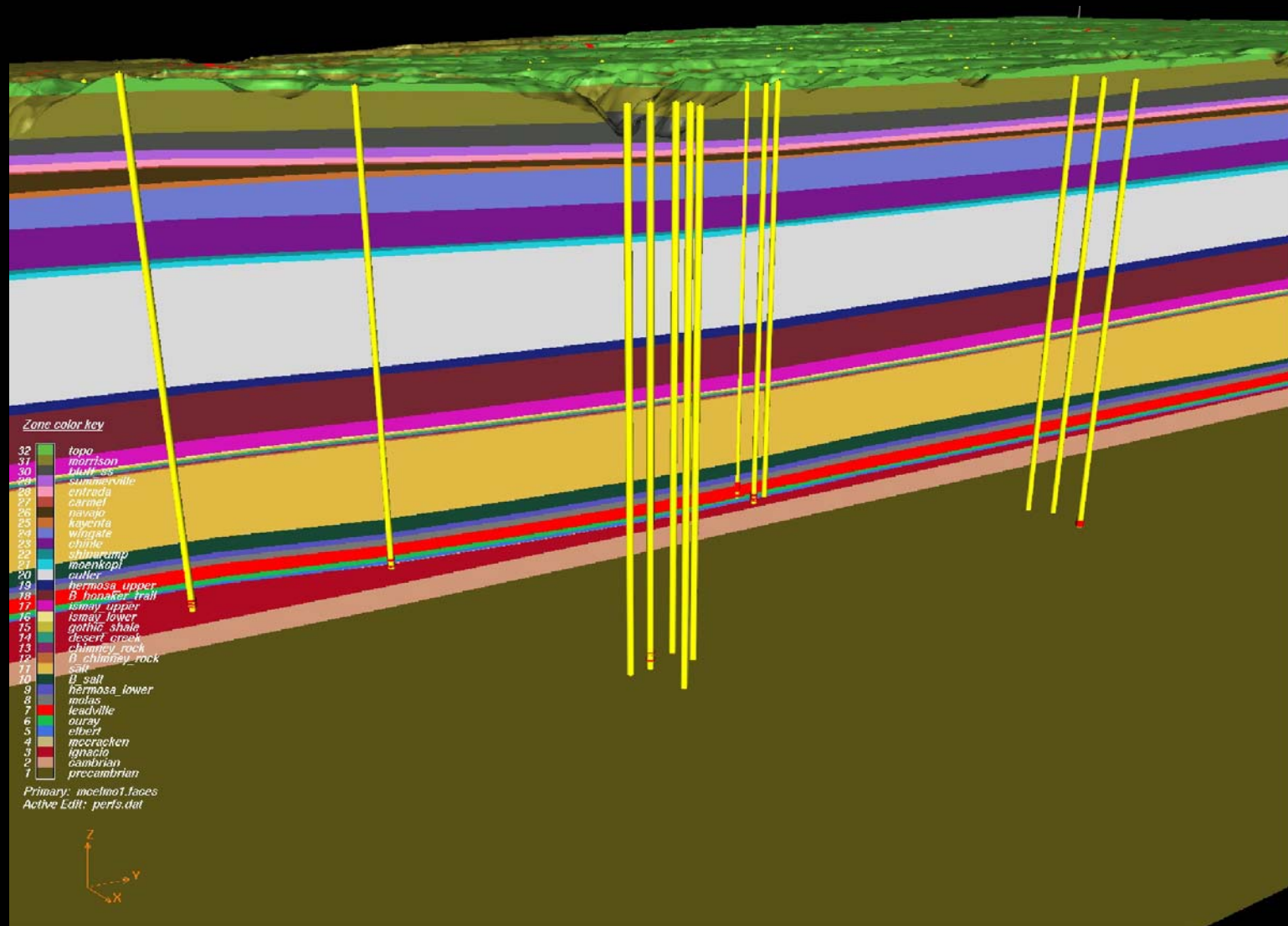
Preliminary EarthVision geologic model of McElmo Dome: system scale



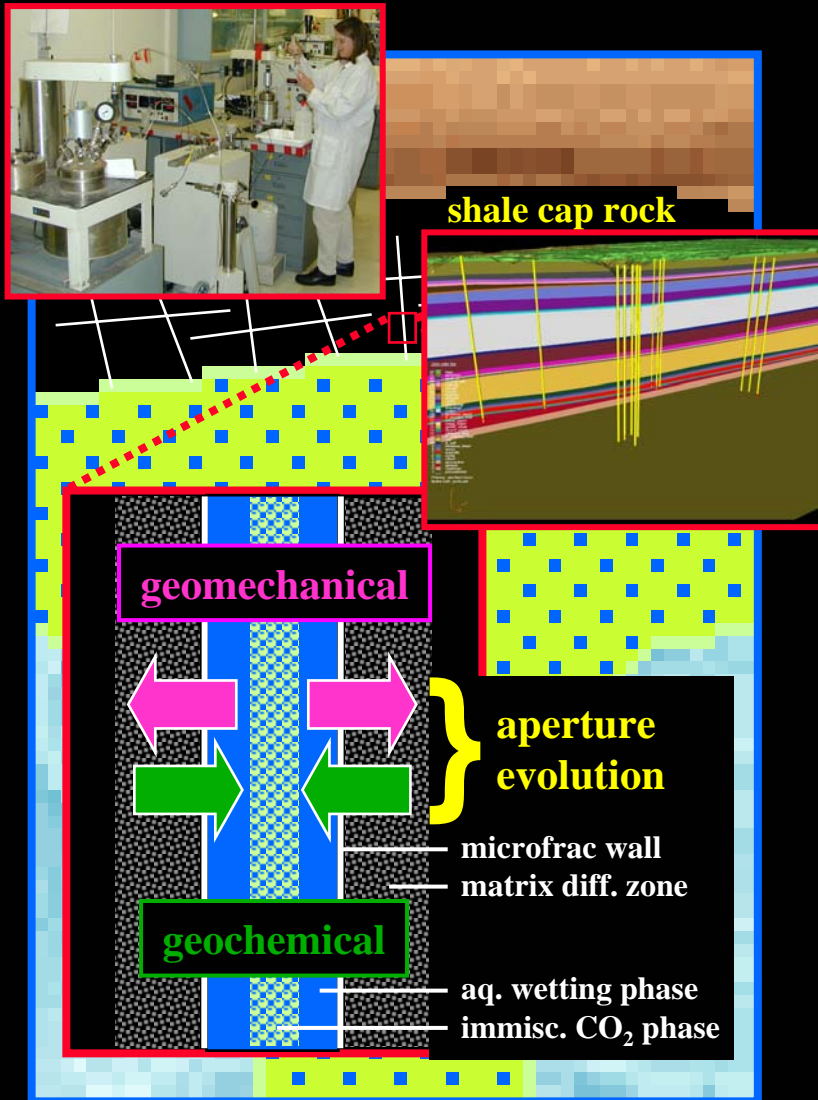
Preliminary EarthVision geologic model of McElmo Dome: Leadville structure



Preliminary EarthVision geologic model of McElmo Dome: cross-sections



Enhanced isolation performance of geologic CO₂ storage sites through mineral trapping



- **Goal: confirm key model predictions**
 - ✓ Maintain reservoir integrity
 - ✓ Improve cap-rock seal capacity
- **Experimental assessment**
 - ✓ Batch reactor: from idealized synthetic materials to relevant core samples
 - ✓ Iterative RT modeling to predict & optimize agreement with expt'l results
- **Field assessment**
 - ✓ McElmo Dome (natural CO₂ reservoir)
 - ✓ Evidence of min trapping in shale cap?
 - ✓ RT modeling to predict impact of min trapping on res/cap-rock integrity
- **Long-term field-scale models must be grounded by accurate expt'l forecasts**

Questions



“The single biggest problem in communication is the illusion that it has taken place.”

George Bernard Shaw